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SPATIAL AND TEMPORAL VARIATION OF C– FACTOR AND SOIL EROSION IN A SEMI-ARID WATERSHED: A CASE STUDY IN MAHABUBNAGAR DISTRICT

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ABSTRACT

Identifying the erosion prone areas and estimation of soil loss in the watershed is essential for implementing suitable conservation practices. In the present study, spatial, temporal variation of C-factor and soil erosion was assessed in a micro-watershed, located in Mahabubnagar district using RUSLE, integrated with Remote Sensing and GIS for the period 2001 to 2016. The mean annual erosivity factor (5007.56 MJ mm ha^{-1} h^{-1} yr^{-1}) was derived using daily rainfall data, by adopting standard procedures. The soil erodibility (K) and conservation practice (P) factors in the study area were selected as 0.017 and 0.39, based on watershed geological features. The cover management factor (C) was derived from the MODIS NDVI images of 16 day interval, with 250 m resolution. The results indicated that, the values of the C factor ranged from 0.01 to 0.85 and varied spatially and temporally, depending upon variation in the vegetative cover. The areas having lower NDVI, resulted in higher values of C factor. No considerable variation in mean C factor was observed, during above normal, normal and drought years. The annual soil loss varied spatially from 0.0016 to 15.68 t ha^{-1} $yr^{-1}$and mean annual soil erosion of 1.27 t ha^{-1} yr^{-1}. And the mean annual soil loss was found to be 2.0, 1.16 and 0.69 t ha^{-1} yr^{-1} during above normal, normal and drought years. The obtained results inferred that, major portion of the study area comes under slight erosion category (< 2.5 t ha^{-1} yr^{-1}) and in-situ soil conservation measures (strip cropping, crop rotations, etc.), farm ponds and percolation tanks are recommended for the sustainable management of watersheds.

KEYWORDS: Rainfall Erosivity, RUSLE, Soil Erodibility, Soil Erosion, Topography Factor and Vegetation Cover

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A Case Study

INTRODUCTION

Soil is an essential natural resource, consisting of inorganic and organic matter, which provides structural support, source of water and nutrients for plant growth. It is the most important component of the land and performs many functions such as providing food, fuel, fibre and shelter (Maji, 2007). Therefore, efficient and intelligent management of soil resource is of paramount importance of feeding the growing population. But in the recent years, soil is being subjected to rapid deterioration, due to various natural and anthropogenic activities. Soil erosion is one of the most significant and widespread form of degradation, which has both environmental and economic impacts, especially in agricultural areas (Prasannakumar *et al*., 2011). It is a natural process of detachment of soil particles, from the uppermost layer of soil profile and transporting them elsewhere, by erosive agents such as water or wind (Ganasri and Ramesh, 2015).The removal of fertile soil from the upper layer resulting in the loss of soil nutrients and makes the soil unproductive, which in turn reduces the agricultural productivity at imperceptible rates, over extended periods (Lal, 2003; Dipanwita *et al*., 2015).

Soil erosion has become a great threat, for sustainable agricultural production and water quality in the catchment areas. The eroded soil particles from the upper reaches of the catchment area, increases the deposition of sediments in canals, farm ponds, lakes, rivers and reservoirs and reduce their storage capacity and water quality, by contaminating the water with suspended soil, toxic materials and pesticides (Reddy *et al*., 2005). It has been estimated that in India, about 5334 MT (16.4 t $ha^{-1}yr^{-1}$) of soil is detached annually, about 29% are carried away by the rivers into the sea and 10% is deposited in reservoirs, resulting in the considerable loss of the storage capacity (Narayan and Babu, 1983). As the global population increases, the demands for their food, shelter and standard of living expectations increase, and ultimately there will be more pressure on soil resources, changes in land use and intensive cultivation which accelerates the rate of soil depletion. In India, areas under land degradation have been on the rise, particularly during the last few decades, and the latest estimates showed that, an area of about 120.72 M ha is affected by various forms of land degradation, of which 82.57 M ha is solely accounted for, by water induced soil erosion in excess of 10 t ha^{-1} yr^{-1} (Biswas *et al*., 2015).In this context, spatial and temporal assessment of soil loss is essential for planning the soil conservation interventions for proper management of watersheds.

Earlier researchers have used various models for estimating soil loss at catchment, regional and global scales such as Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), Soil and Water Assessment tool (SWAT), Agricultural Non- Point Source Pollution Model (AGNPS).The RUSLE has been widely adopted for soil loss estimation at the watershed scale, because of its convenience in computation and application (Balasubramani *et al.,* 2015).Although, it is an empirical model, the combined use of remote sensing, Geographical Information System (GIS) and RUSLE techniques makes soil erosion estimation and its spatial distribution feasible within reasonable costs and better accuracy, in larger areas(Rejani *et al*., 2016).RUSLE computes the average annual soil loss from the catchment using factors, such as rainfall runoff erosivity (R), soil erodibility (K), topography(LS), cover management(C) and conservation practice(P).The present study focuses on the estimation of spatial and temporal variation of C-factor and soil erosion in a semi-arid watershed of Mahabubnagar district, using RUSLE coupled with GIS and its application, for the sustainable management of the watershed.

MATERIALS AND METHODS

Study Area

The watershed is located in Mahabubnagar district, Telangana and extends from 16°52′51″N to 16°58′58″N latitudes and 77°59′36″E to 78°6′4″E longitudes, with elevation ranges from 525 to 663 m above mean sea level (Figure 1).The study area receives an average annual rainfall of 629 mm, from South, West and North East monsoons. It falls under the Krishna River basin and drains the water from a catchment area of 6927 ha. The major portion of the study area is characterized under loamy, followed by clayey soils whose infiltration rates are moderately low to low.

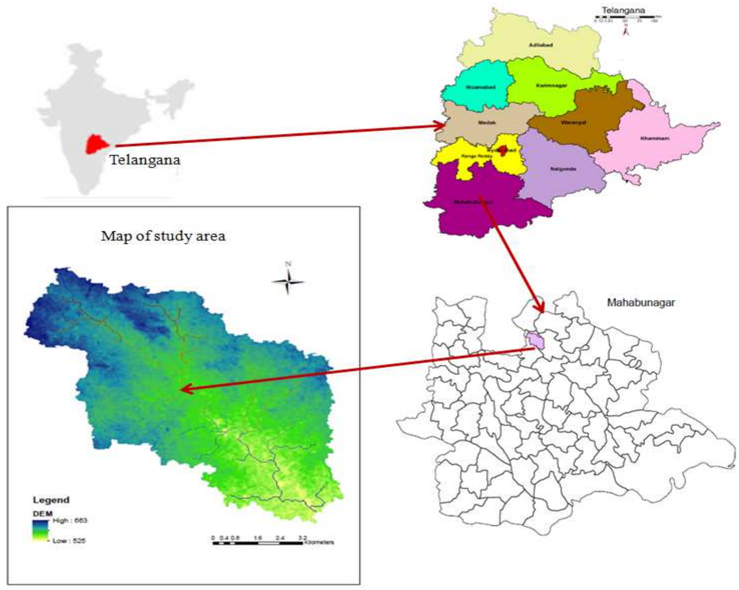

Figure 1: Location and Digital Elevation Maps of the Watershed

METHODOLOGY

The watershed is extracted from ASTER DEM using hydrotools in Arc Map10.3 software.Flow accumulation and slope maps were derived from ASTER DEM. Soil map from National Bureau of Soil Survey and Land Use Planning (NBSSLUP), and daily rainfall data forthe period from 2001 to 2016,provided by Directorate of Economics and Statistics (DES), Hyderabad wereutilized.The spatial and temporalvariation of soil loss from the semi-arid watershed over 16 years was estimated, using the Revised Universal Soil Loss Equation (RUSLE),combined with Remote sensing and GIS. RUSLE, whichis a function of five factors: rainfall erosivity (R), soil erodibility (K), slope steepness (LS), cover management (C) and conservation practice (P). These factors vary over space and time (Prasannakumar *et al*., 2012). RUSLE (Renard *et al*., 1997) can be expressed as:

$$A= R*K*LS*C*P \quad (1)$$

Where, A = Average annual soil loss (t $ha^{-1}yr^{-1}$)

R = Rainfall erosivity factor (MJ mm ha^{-1} $h^{-1}yr^{-1}$)

K = Soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1})

LS= Slope length-steepness factor (dimensionless)

C= Crop cover management factor (dimensionless)

P =Conservation practices factor (dimensionless)

The methodology used in the present study is show in the figure cited below:

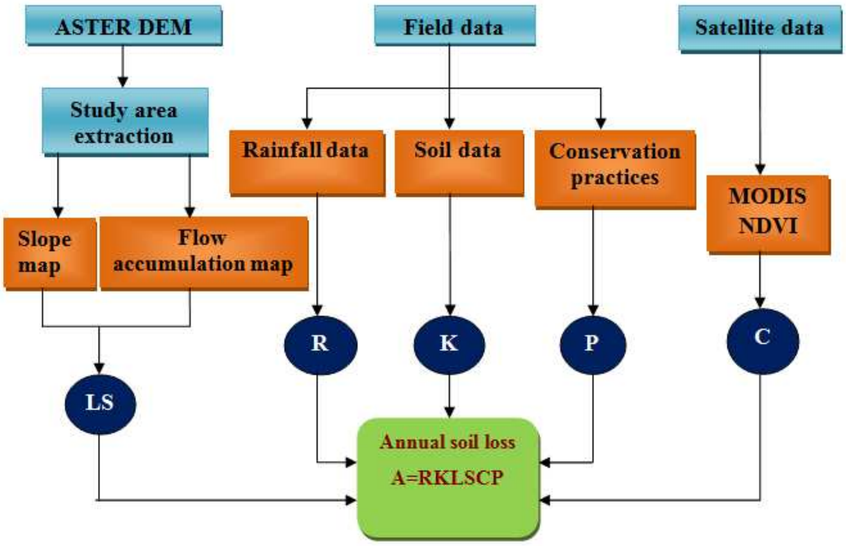

Figure 2: Flow Chart for Estimation of Soil Erosion using RUSLE Integrated with GIS

Rainfall Erosivity Factor (R)

It is a measure of the erosive power of a rainfall and also reflects the amount and rate of runoff, likely to be associated with the rainfall (Ganasri and Ramesh, 2015). In this study, rainfall data for the period from 2001 to 2016 were collected from DES, Hyderabadand used to calculateR-factor, with the procedure reported by Rejani *et al*., 2016.

$$R = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} EI_{30}}{n} * 1000/200.6 \tag{2}$$

Where, R = Average annual erosion index (MJ mm$ha^{-1}h^{-1}yr^{-1}$);

i= Number of years;

j= number of days per year, i;

EI_{30} = Rainfall erosivity at 30 minutes per day (hundreds t cm $ha^{-1}h^{-1}$)

$$EI_{30} = 34.065\ EI_{1440} - 0.2695 (R^2 = 0.83) \tag{3}$$

Where, EI_{1440} = Erosion index per day (hundreds t cm ha h^{-1})

$$EI_{1440} = 3.856\ PI_{1440} - 0.0048 (R^2 = 0.89) \tag{4}$$

Where, PI_{1440} = Daily precipitation index, cm^2h^{-1}

$$PI_{1440} = (\text{Rainfall})^2/24 \tag{5}$$

Where, the rainfall is in cm.

The rainfall analysis was also carried out and the years, having the mean annual rainfall > +19% was classified as above normal year, -19 to +19% was classified as normal and < -19% as drought year (Rejani *et al*., 2015a).

Soil Erodibility Factor (K)

Soil erodibility (K) refers to the inherent susceptibility of soils to erosion, by raindrop impact and runoff and it reflects the physical and chemical properties of soils affecting detachability, transportability, aggregate stability and

infiltration capacity (Prasannakumar *et al*., 2011; Farhan *et al*., 2013). In this study, soil texture map (Figure 2) was derived from the soil map, prepared by NBSSLUP, Govt. Of India and the major portion of the study area was found to bedeep clay, followed by deep loamy soils, and then corresponding K values were selected by the report of Reddy *et al*., 2005.

Topographic Factor (LS)

The topographic factor is the expected ratio of soil loss per unit area, from a field slope to that from a 22.13 m length of uniform 9 % slope, under identical conditions (Shinde *et al*., 2010; Balasubramani *et al*., 2015). It represents the effect of topography on erosion. The LS factor map was generated from slope and flow accumulation maps, which are derived from ASTER DEM using the following equation (Rahaman *et al*., 2015; Rejani *et al*., 2016):

$$LS = \left[\frac{Flowaccumulation * Cellsize}{22.13} \right]^m * (0.065 + 0.045 * S + 0.0065 * S^2) \tag{6}$$

Where, S is the value of slope grid in percentage, cell size is the resolution of the DEM and m is a dimensionless constant, which depends upon the slope. Slope of the study area ranges from 0 to 34 degrees (Figure 3), but the major portion of the area has slope less than 5degrees and some specific areas only showing higher slope. Hence, for this study value of m ranges from 0.3 to 0.5.

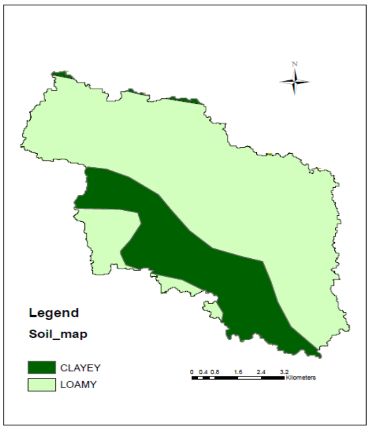

Figure 3: Soil Map of the Study Area

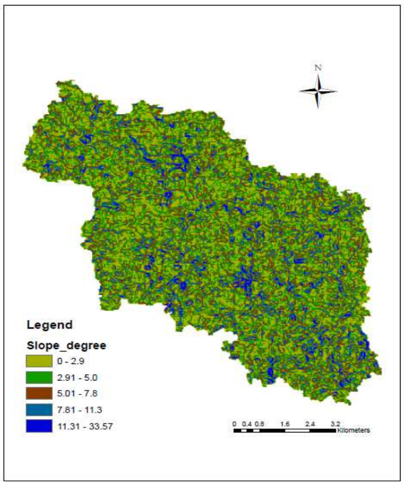

Figure 4: Slope Map of the Study Area

Cover management Factor (C)

Cover management factor indicates the effect of vegetation and management practices, on the soil erosion rate. It is defined as the ratio of soil loss from land maintained under specified conditions, to the corresponding loss from clean tilled and continuous fallow. The value of C factor depends on the type of vegetation and percentage of vegetation cover, which protects the soil by dissipating the raindrop energy before reaching the soil surface (Patil*et al*., 2013). It varies from 0, for well protected soils to 1 for bare soils (Prasannakumar *et al*., 2011; Tirkey *et al*., 2013).Normalized Difference Vegetation Index (NDVI), is a best indicator for detecting and interpreting the vegetation cover, and in the present study, MODIS images having a spatial resolution of 250 m (MOD13Q1) were downloaded from the website: https://lpdaac.usgs.gov/data_access/daac2disk, which consists of multispectral layers. From these multispectral images, the NDVI maps were extracted, whose values of NDVI ranges from 0 to 1. Very low values (0.1 and below) of NDVI correspond to barren areas of rock, sand, or snow. Moderate values (0.2 to 0.3) represent shrub and grassland, while high values (0.6 to 0.8) indicate dense vegetation cover. Then C factor maps were generated, using the following expression in spatial analyst raster calculator.

$$C = \exp\ [-\alpha * \frac{NDVI}{(\beta - NDVI)}]- \quad (7)$$

Where, α and β are dimension less parameters, that determine the shape of the curve relating NDVI and the C factor and taken as 2 and 1 respectively from the literature (Lulseged Tamene and QuangBao Le, 2015; Rejani *et al*., 2016). Monthly C factor maps were generated by taking the mean of every two composites, of that corresponding month. Likewise, it was done in the period from 2001 to 2016 in order to estimate the spatial and temporal variation of C factor, within the study area. C factor varies from 0 to 1 for well protected soils, which are fully covered by vegetation to barren lands, without any vegetation. The spatial variation of maximum C factors, along with corresponding variations in maximum NDVI values were observed for the above normal, normal and drought years for different land uses like *kharif* crops, current fallows and scrub lands.

Conservation Practice Factor (P)

It depicts the effect of conservation practices such as strip cropping, contour cultivation and contourbunding and terracing, which reduce the erosion potential of runoff. Its value varies from 0 to 1, for good conservation practice to poor conservation practice. For the proposed study, the P factor was derived from the land use, land cover map and the support practices, followed in the selected area (Reddy *et al*., 2005; Rejani *et al*., 2016). In the selected semi- arid watershed area, contour cultivation has been followed as a soil conservation method and hence the value of P factor was considered as 0.39.

RESULTS AND DISCUSSIONS

Rainfall Erosivity Factor (R)

Out of 16 years, five years were above normal, seven years were normal and four years were drought years. Based on rainfall data, the mean annual rainfall during above normal, normal and drought years was found to be 845, 584 and 435 mm respectively. The annual erosivity varied from1848.31 MJ mm ha^{-1} $h^{-1}yr^{-1}$to 8892MJ mm $ha^{-1}h^{-1}yr^{-1}$, with a mean value of 5007.56 MJ mm $ha^{-1}h^{-1}year^{-1}$. Even though, the rainfall in the year 2008 is less (847.75 mm), as compared to corresponding rainfall in 2013, the erosivity obtained is same for both the years, which indicate that, the erosivity mainly depends on the intensity of rainfall rather than the total amount of rainfall. Therefore, hourly or daily rainfall data were

preferable for accurate estimation of temporal variation of erosivity, than monthly or annual rainfall data.

Soil Erodibility Factor (K)

The K factor values, for the study area ranged between 0.015 to 0.033 t ha h $ha^{-1}MJ^{-1}mm^{-1}$ (Reddy *et al*., 2005). The lower value of K factor is associated with the soils, having low permeability and higher value for soils, having a higher permeability. Since, the major portion of the study area was characterized as clay (Figure 3), the K value was takenas 0.017 t ha $hha^{-1}MJ^{-1}mm^{-1}$.

Topographic Factor (LS)

Since, the most of the study area falls under the slope of less than 5 degrees, value of dimensionless constant (m) was assumed as 0.3. Using the equation (6), along with the slope map and the flow accumulation map in raster calculator in Arc Map 10.3, the LS factor map was derived and observed that, the value of the LS factor varied from 0 to 8.9, with a mean value of 0.20 for the selected watershed. The majority of the study area has LS value, less than 0.5 (Figure 6).

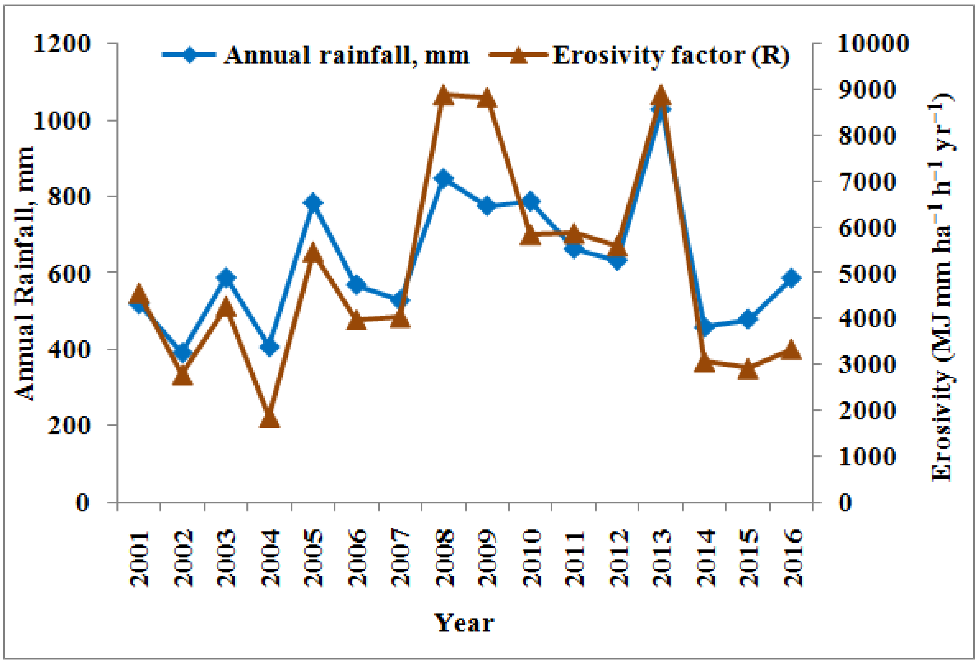

Figure 5: Temporal Variation of Annual Rainfall and Erosivity for the Period from 2001 to 2016

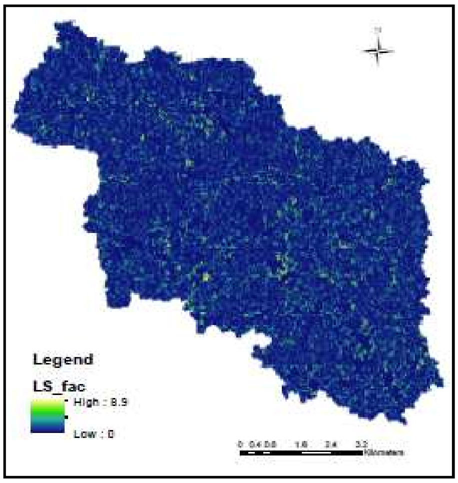

Figure 6: Topography Factor (LS) Map of the Study Area

Spatial and Temporal Variation of NDVI and Cover Management Factor (C) in above Normal, Normal and Drought Years

From the land use, land cover map (NRSC, Hyderabad) of the study area, it was found that, the major part of the watershed area was classified under *kharif* crops, followed by *Zaid* crops and current fallows. Higher NDVI values were observed during the mid *kharif* season (i.e., in the months of August to September), and lower NDVI values were observed after harvesting the crops (Figure 7).The C factor varied spatially and temporally, depending upon variation in vegetation cover. The values of the C factor were ranged from 0.01 to 0.85. The areas having lower NDVI values, obtained higher values of C factor (Figure 8 and 9).

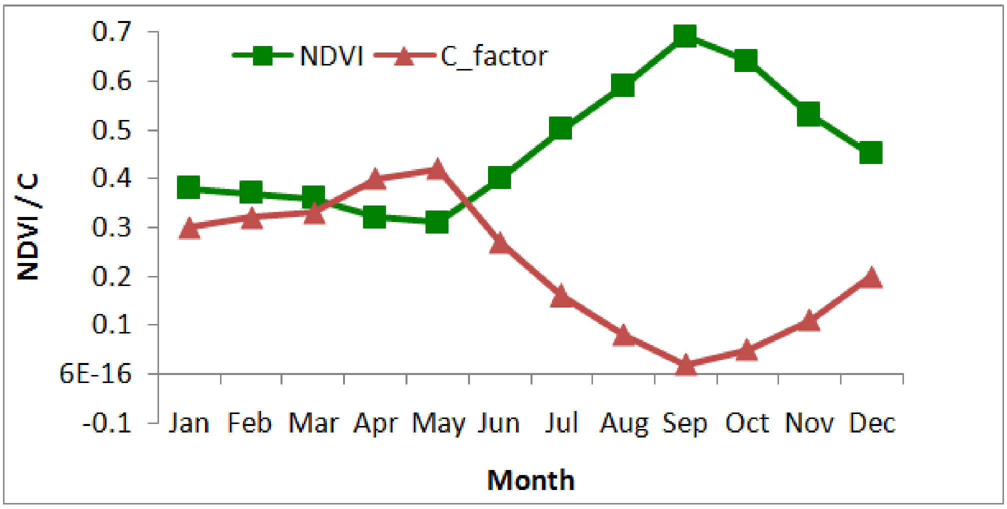

Figure 7: Temporal Variation of NDVI and C Factor Values of the Year 2013

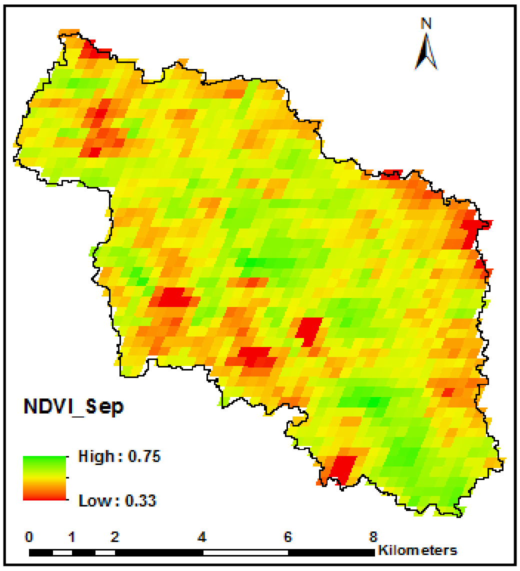

Figure 8: Monthly NDVI Map of the Study Area

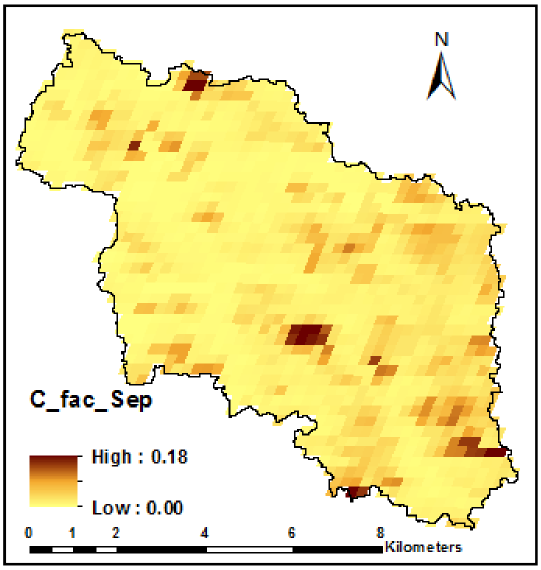

Figure 9: Monthly C-Factor Map of the Study Area

The spatial and temporal variation of maximum C factors, to corresponding variation in maximum NDVI ,over major land use classes like *kharif* crops, current fallows and scrub lands, during June to December were compared among the drought year (2004), normal (2005) and above normal (2013) year (Figure 10,11 and 12).

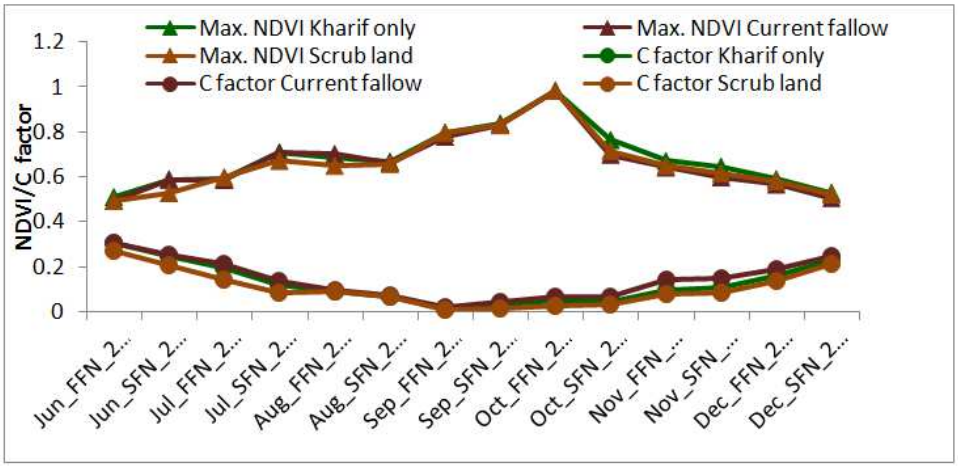

Figure 10: Variation of Maximum NDVI and C Values during Above Normal Year (2013)

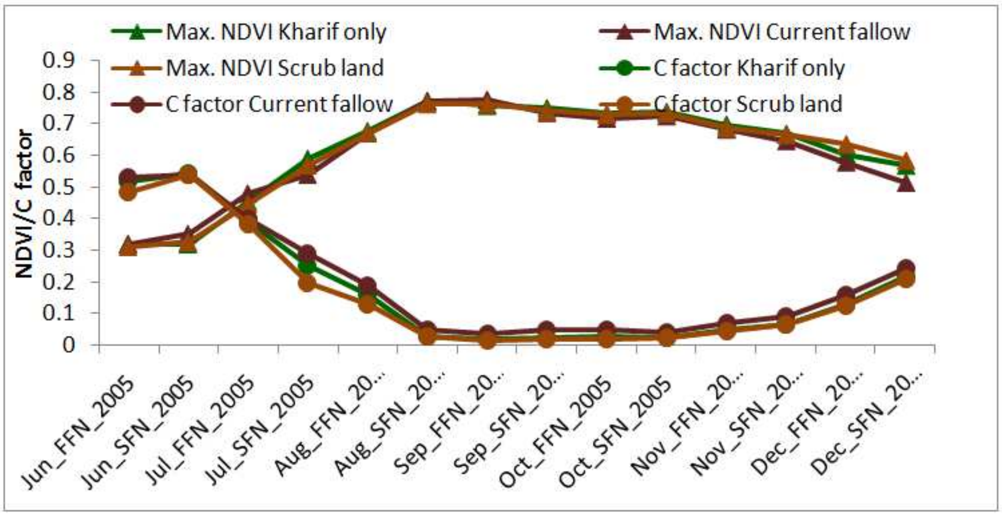

Figure 11: Variation of Maximum NDVI and C Values during Normal Year (2005)

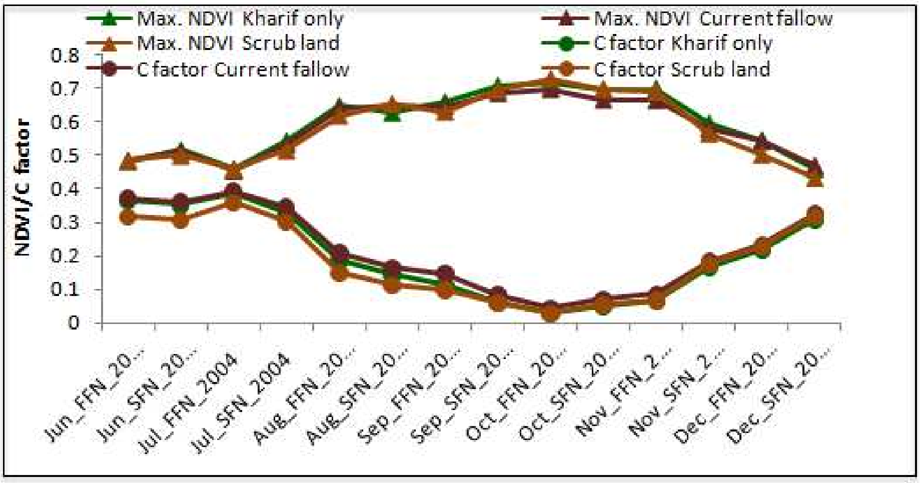

Figure 12: Variation of Maximum NDVI and C Values during Drought Year (2004)

The results revealed that, both the values of NDVI and C factor were found to be similar for all the three land use classes in above normal, normal and drought years. The maximum values of NDVI were observed during the first

fortnight(FFN) of October (Figure 10), second fortnight (SFN) of August (Figure 11) and the first fortnight (FFN) of October (Figure 12) in above normal (2013), normal (2005) and drought (2004) years, respectively. The minimum values of the C factor were observed during the first fortnight (FFN) of September, in both the above normal (2013) and normal (2005) years, and the first fortnight (FFN) of October in and drought (2004) years. The variability of C factor may be contributed by variation of NDVI values, over the period. Using a single value of C factor, may result in the loss of information, hence, it was suggested to use C factor based on NDVI values.

Spatial and Temporal Variation of Soil Loss

Monthly soil loss and annual soil loss maps were generated, to estimate the temporal and spatial variation of soil loss, over the period of 16 years (2001 to 2016). It was found that, the potential annual soil loss from the semi-arid watershed varied from 0.62 (2002 and 2015) to3.11 t $ha^{-1}yr^{-1}$(2010).From the results, it can be noted that, average annual soil loss over the 16 year period, varied from 0.002 to 15.68t $ha^{-1}yr^{-1}$, with a mean value of 1.27 t $ha^{-1}yr^{-1}$ and a standard deviation of 1.60 (Figure 13).And also, the mean annual soil loss was observed as 2.0, 1.16 and 0.69 t ha^{-1} yr^{-1} during above normal, normal and drought years. The regions or watersheds were prioritized, on the basis of soil loss into four classes, namely, priority I, II, III, and IV with soil loss greater than 40, 20 to 40, 15 to 20 and less than 15 t $ha^{-1}yr^{-1}$, respectively (Reddy *et al*., 2005; Rejani *et al*., 2015b; Rejani *et al*., 2016), and various *in-situ* conservation methods were also recommended. The selected watershed comes under priority IV class, therefore, along with contour cultivation, other *in-situ* conservation methods like strip cropping viz., growing erosion resistant crops (groundnut) with erosion permitting-crops, such as jowar, crop rotations, mulching, planting of grasses for stabilizing bunds, deep ploughing, summer ploughing, mixed cropping and structures like farm ponds and percolation tanks, are recommended for sustainable management of the watershed.

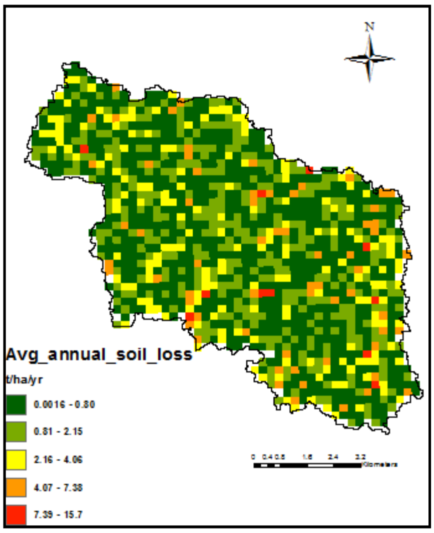

Figure 13: Spatial Variation Soil Loss within the Study Area

CONCLUSIONS

In the present study, the GIS coupled with RUSLE were used, for estimating the spatial and temporal variation of soil loss, within a semi-arid watershed of Mahabubnagar district. The variation of C factor was also analyzed. The high intensity rainfall events, resulted in higher values of erosivity factor in the year 2008 and 2013. Since, most of the study area includes only *kharif* crops, higher NDVI values were observed, during the *kharif* season (June to September).As the

NDVI value increases, decrease in the values of C factor was observed, which indicates the decrease in the rate of soil loss. Instead of using single value of C factor, it was suggested to use C factor, based on NDVI value to acquire more information about the watershed. The mean annual soil loss was observed 2.0, 1.16 and 0.69 t ha^{-1} yr^{-1} during above normal, normal and drought years. The selected semi-arid watershed falls under priority VI class, with an average annual soil loss less than 1.27 t $ha^{-1}yr^{-1}$. Therefore, *in-situ* conservation measures such as strip cropping, crop rotations, mulching, planting of grasses for stabilizing bunds, deep ploughing, summer ploughing, mixed cropping are suggested for sustainable management of soil. Farm ponds and percolation tanks are to be designed, to harvest the available water, which may result in the increased water table in the surrounding areas.

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